

THE EFFECTS OF EXTENDED BED REST ON
HUMAN SLEEP PATTERNS

BY

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TABLE OF CONTENTS

CHAPTER	PAGE
ACKNOWLEDGEMENTS	iii
ABSTRACT	vii
ONE INTRODUCTION	1
Sleep as a Biological Rhythm	1
Uniphaseic or Ultradian ?	4
TWO METHODS	12
THREE RESULTS	15
Initial Sleep Period	15
Bedrest Period	17
Circadian Considerations	24
FOUR DISCUSSION	33
Total Sleep Time	35
Uniphaseic or Ultradian?	49
APPENDIX	
SLEEP QUESTIONNAIRE	53
REFERENCES	55
BIOGRAPHICAL SKETCH	60

LIST OF TABLES

TABLE		PAGE
I	Comparisons of sleep stage characteristics for baseline (Night 2), bedrest period, and normative group.	16
II	Individual and group statistics for the bedrest period (BP)	20
III	Distribution of bedrest sleep periods by the presence or absence of REM and Stage 4 sleep.	21
IV	Comparison of sleep variables as a function of night (11 PM - 7 AM) and day (7 AM - 11 PM).	25
V	Sleep onset times of longest sleep episodes for Night 2 (baseline), 3, and 4.	28
VI	Comparison of sleep variables between first and second 24 hours of bedrest period.	31

LIST OF FIGURES

FIGURE		PAGE
1	Placement of sleep/waking episode across 60 hours for individuals and group.	18
2	Example of sleep across BP (#932).	19
3	Total number of subjects asleep, for each hour across the bedrest period.	26
4.	Proportions of TST spent in REM sleep, as a function of time of day.	29

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That the sleep response is one of numerous physiological functions which may be classified as a biological rhythm is well-established. Less well-founded, despite its popularity, is the notion that the sleep of adult humans maintains an inherent tendency to occur monophasically within each 24 hours, typically during the nocturnal portion of the 24-hour day.

This dissertation addresses the hypothesis that self-imposed and/or sociophysically mediated behavioral controls have a significant influence on the manifestation of such a uniphaseic sleep pattern, and that attenuation of behavioral controls may result in a "loosening" of the circadian framework of typical adult sleep.

Each of 9 young adults was electrographically recorded over a period of 60 hours, during which behavior was restricted primarily to lying quietly in bed; i.e., subjects were not permitted to read, write,

listen to music, watch TV, exercise, etc. Meals were served at random intervals, and subjects had no knowledge of time of day throughout the bedrest period (BP).

The data indicate that a reduction in behavioral controls, which typically influence the sleep process, results in substantial alterations in the placement and periodicity of sleep. Sleep episodes became evenly dispersed across the 24-hour day, resulting in an approximate 6 hour sleep/waking cycle.

While the average sleep period duration decreased, mean total sleep time for the bedrest period (28 h) exceeded, by more than 40%, that which would be expected under the assumption of a uniphasic sleep/waking rhythm. The continued tendency toward a nocturnal weighting of total sleep was clear, however, since 55% of TST for BP occurred during the night (11PM to 7AM).

Within sleep structure (e.g., sleep stage percentages, mode of appearance) was affected only slightly by the "loosening" of the sleep response. REM sleep retained its tendency to occur differentially across the 24-hour day; stage 4 sleep appeared to maintain its relationship to prior wakefulness.

It is suggested that the sleep/waking patterns observed in this study may be further manifestations of an inborn (albeit, highly dampened) ultradian sleep/waking rhythm.

CHAPTER ONE INTRODUCTION

Sleep as a Biological Rhythm. That the sleep response is one of a vast array of physiological functions which maintain a reliable tendency to repeat at regular intervals has been demonstrated on numerous occasions over the past two decades (see for example, Aschoff, 1965; Richter, 1965; Symposia on Quantitative Biology, 1960; Webb, 1971; Webb and Agnew, 1974a). That the modulation of the sleep/waking cycle is controlled by innate and autonomous mechanisms seems, also, to have been well established.

In a free-running (time free) environment, subjects display the continuation of a sleep/waking rhythm which deviates slightly from the standard 24 hours (usually longer). The only plausible explanation for such a finding, according to Aschoff (1965, p. 1427) is "that this rhythm is not imposed on the organism by the environment, but is truly endogenous. We are dealing with a self-sustaining oscillation which is free-running under constant conditions and has its own inherent frequency."

The autonomous nature of the sleep/waking rhythm may also be demonstrated in the free-running environment, relative to other rhythms. The vast majority of rhythms which are in phase with the sleep/waking cycle in the 24-hour environment become desynchronized upon introduction into the time free environment (Aschoff, 1978; Aschoff and Wever, 1976; Wever, 1973). An example of such

desynchronization is that which occurs between the temperature and sleep/waking rhythms. When both rhythms are entrained to 24 hours, the maximum temperature typically occurs just prior to retiring, and the minimum temperature occurs toward the end of the sleep period. However, under free-running conditions, maxima and minima of rectal temperatures become independent of sleep onset and termination.

In addition, the sleep/waking rhythm may be entrained to artificial light/dark regimens while typically in-phase rhythms maintain their free-running periodicities. For example, throughout 10 days of entrainment to a 3 hour sleep/waking cycle, subjects' temperatures continued to exhibit characteristic circadian periodicities (Weitzman, Nogueira, Perlow, Fukushima, Sassin, McGregor, Gallagher, and Hellman, 1974). Such data "contradict any hypothesis of a simple 'cause-and-effect' relationship between the activity-rest cycle and the rhythm of body temperature, and suggest a system of two coupled oscillations . . . with a mutual phase relationship which depends on the conditions" (Aschoff, 1978; p. 740).

Further evidence of the sleep/waking cycle's autonomy relative to other biological rhythms may be seen in the results of sleep deprivation studies. In the absence of sleep (for more than 70 hours) measures of performance, temperature and endocrine function all showed continuation of endogenous circadian rhythms (Murry, Williams, and Lubin, 1958; Froberg, Karlsson, Levi, and Lidberg, 1975, as cited by Aschoff, 1978).

Examinations of the maturation of the human sleep/waking rhythm have also provided evidence for its innate and autonomous nature.

After observing the development of an initial 25-hour periodicity in an infant maintained on a self-demand sleep-wakefulness and feeding schedule, Kleitman and Engelmann (1953) concluded that "there may be a 'natural' rhythm which only has to be adjusted to the 24 hour alternation of night and day" (p. 280). Other researchers have also observed the development of adult-like, primarily monophasic, nocturnally placed sleep under similar conditions of self-demand feeding (Parmelee, Wanner, and Schulz, 1964; Salzarulo, Fagioli, Salomon, Ricour, Raimbault, Ambrosi, Cicchi, Duhamel, and Rigoard, 1980).

While the sleep/waking rhythm clearly appears to be inborn and independently regulated, it may, at the same time be entrained by exogenous Zeitgebers, to frequencies other than those characteristic of the free-running environment. It has been demonstrated that human subjects are capable of maintaining sleep/waking cycles of various lengths, quite efficiently within a range of about 20 to 27 hours, as the result of entrainment to appropriate light/dark regimens. It has been further shown that the sleep/waking rhythm characteristic of a free-running environment may be regulated by "rigid control of the sleep portion of the cycle . . . particularly of the wakeup time" (Webb and Agnew, 1974b; p. 701).

Several investigators also point to the developmental literature as a source of evidence for the entrainability of the sleep/waking rhythm (Ellingson, 1975; Gesell and Armatruda, 1945; Kleitman, 1963; Sander, Stechler, Burns, and Julia, 1970; Sterman, 1979). As expressed by Sterman (p. 213), "the development of sleep is a postnatal

phenomenon, subject both to the dictates of physiological maturation and the influences of environment. Such factors as geography and social custom entrain the physiological substrates of the sleep-waking cycle to determine the behavioral patterns which will come to characterize these states in a given culture."

Indeed, the very fact that adult humans maintain a 24-hour sleep/waking periodicity, in spite of an inherent rhythm with a frequency longer than 24 hours, is clear evidence of the entrainability of the rhythm.

It appears then, that the oscillation between sleep and wakefulness, characteristic of adult human subjects, meets the criteria necessary for its designation as a biological rhythm. Sleep is an inborn, independently regulated, exogenously entrainable, regularly occurring response.

Uniphasic or Ultradian? While sleep and wakefulness clearly comprise a physiological system which may be classified as a biological rhythm, determination of the rhythm's inherent periodicity remains less clear, since few studies have been conducted which adequately address this point. It is generally assumed that the sleep/waking cycle is an uniphasic one. In addition to the obvious support for such a notion, i.e., that adult humans typically obtain sleep in a single, nocturnal block, results from studies in which the normal sleep period has been dispersed or eliminated have also been cited as evidence for this view. In such experiments, performance measures are usually lowest and subjective reports of sleepiness are

usually greatest during the interval in which the subject would normally be sleeping (Colquhoun, 1971; Weitzman et al., 1974).

It has further been reported (Weitzman et al., 1974) that "a striking persistence of a circadian pattern of total sleep time" (p. 1020) was exhibited throughout 10 days of entrainment to a 3-hour day. In this study, subjects were encouraged to sleep 1 hour out of each 3 hours. The authors reported that the 4 sleep periods beginning at 3 AM, 6 AM, 9 AM, and noon accounted for 70% of the total sleep time.

The decreased sleep efficiency associated with dispersed and displaced sleep schedules has also been seen as lending support to the notion of an inborn, nocturnally placed, uniphasic system of sleep and wakefulness. Studies in which the normal, nocturnal sleep period has been shifted to a time typically employed for work or other waking activities, indicate that such sleep episodes are characterized by significantly greater proportions of wakefulness (stage 0) after initial sleep onset, as compared to baseline (normal) sleep (Webb, Agnew, and Williams, 1971). Such findings suggest that the maintenance of sleep is more difficult when the sleep period is shifted from its typical, nocturnal placement. Further, as experimentally circumscribed 'days' deviate from the normal 24 hours, sleep efficiency (amount of time in bed spent asleep), becomes less. Webb and Agnew (1975) found that subjects maintaining a sleep/waking schedule of 3 hours sleep/6 hours wakefulness only achieved 80% sleep efficiency when compared to baseline conditions (8 hours sleep/16 hours wakefulness). Weitzman et al. (1974) reported 56% sleep

efficiency for subjects attempting a 3-hour cycle compared with 90% efficiency for the baseline condition.

It has also been noted in dispersed, as well as displaced sleep, that the intrasleep structure of the "new" episodes differs in several details from that seen in normally occurring nocturnal sleep. For example, Weitzman et al. (1974) observed "early" REM periods (preceded by less than 10 minutes stage 2 at sleep onset) and "sleep onset" REM periods (preceded only by wakefulness or stage 1) in over half of all REM episodes recorded over the 10 days of 3-hour sleep/wake scheduling. Results of the displacement of subjects' typically nocturnal sleep into day sleep include significant increases in the amount of stage 1 and reductions in the amounts of stages 3 and 4 (Webb and Agnew, 1978). Such findings lend further support to the view that these sleep episodes differ substantially from endogenously modulated sleep periods.

It may be argued, however, that studies of sleep dispersion and and displacement do not adequately address the question of the inherent frequency of the sleep/waking cycle. Rather, such studies more specifically test the entrainability of the presumed uniphasic rhythm. Failure to effectively impose a shortened regimen upon a hypothesized uniphasic rhythm does not necessarily rule out the existence of an ultradian sleep/waking rhythm. Yet, data supporting such a possibility are not extensive.

One type of evidence used to support the suggestion that the human sleep/waking rhythm is inherently ultradian is provided by the analysis of sleep patterns of individuals participating in Polar expeditions. Lewis (1961; Lewis and Masterton, 1957) has suggested

that given a situation in which adherence to customary circadian scheduling is less stringently controlled, a more accurate reflection of the inborn sleep/waking rhythm may emerge.

In the Polar regions the photoperiod is not diurnal, but seasonal. Further, expeditions into these regions typically maintain little resemblance to an organized community, in that there are few circumscribed daily routines, no specific feeding schedules, few timetables (Lewis, 1961). Sleep records from 5 Polar campaigns suggest that the organization of sleep/waking patterns was a direct function of the stringency with which the "community" was structured. For example, members of the British North Greenland Expedition (1952-54) were allowed to sleep as long as they liked, at virtually any time they had the inclination to do so. Under such conditions, sleep durations per 24 hours did not increase substantially over baseline amounts. Yet, the length and placement of individual sleep episodes showed considerable deviations from members' normal sleep habits recorded in England. The tendency toward polyphasic sleep placement was most extreme during the three months of continuous light or darkness. "During these periods . . . men used any of the 24 clock-hours for sleep. The winter months were characterized by many interruptions to sleep and by the taking of naps" (Lewis, 1961, p. 325). Although no data were presented relative to the rhythmicity of these multiple sleep episodes, it appears that the uniphasic "nature" of the sleep process loosened somewhat under conditions of limited environmental cues and negligible behavioral and cultural restraints.

Within the more structured hours of daily life, it has been suggested that the ultradian nature of sleep and wakefulness may be manifest in the form of naps (Webb, 1978). Webb's proposal that naps are part of an inborn sleep/waking rhythm is based on the contention that certain characteristics of these intermittent sleep episodes match features which are common to biological rhythms in general. Specifically, it is maintained that naps are: 1) temporally repetitive, 2) species specific, 3) often developmental, 4) innate and unlearned, 5) endogenous, and 6) adaptive. While evidence seems to support the first four characteristics, and only post hoc speculation can address the sixth, Webb points out that experimental support for the claim that naps are endogenously mediated is extremely limited, and that further data are "likely to be slow forthcoming." This is due primarily to the fact that virtually all procedures utilized for the examination of presumed biological rhythms have prohibited other-than-circumscribed sleep episodes as a consequence of experimental design considerations. Such experiments typically focus on the interactions of major components of sleep, waking and performance. As such, "the very nature of naps in these designs are uncontrolled and interfering sources of experimental variance" (Webb, 1978 p. 316). Two primary designs of this type are the free-running and bedrest procedures.

It has been noted that the sleep/waking rhythms maintained by subjects in free-running environments provide excellent support for the notion that such rhythms are innately and independently controlled. Under such conditions, time cues are removed from the

environment, but other behavioral controls are typically left unaltered. That is, subjects are asked to lead a "normal" life, including eating three meals a day in normal sequence, having the opportunity for exercise and other activities such as reading, writing, watching TV, etc., and maintaining circumscribed sleep schedules (no naps). As a result, these subjects have a tendency to carry on day-to-day life in a manner to which they have grown accustomed over the years. Clearly, such circumstances may strongly bias behavior toward a circadian schedule, perhaps entraining an inherently ultradian rhythm to an environmentally and culturally modulated circadian framework. These factors notwithstanding, the sleep patterns displayed by subjects in time free environments have been seen as providing evidence not only for the biological basis of the sleep/waking rhythm, but for its circadian (uniphase) nature, as well.

The latter inference seems tenuous, at best. For, when controls on the number and placement of sleep episodes are reduced in free-running environments, evidence seems to indicate that the "normal sleep pattern" (single sleep period of from 7 to 10 hours with occasional napping) is modified. Webb and Agnew (1974a) reported that under such circumstances "a significant increase in both long and short periods of sleep, compared to the 24-hour environment" (p. 620) resulted. While neither the placement nor the periodicity of the increased episodes was analyzed, the authors concluded that such changes in the sleep response showed the extent to which the uniphase sleep pattern is disrupted by reduced controls on sleep placement.

While studies employing a bedrest design may clearly eliminate some behavioral controls left in tact by the free-running design (most notably physical exercise), this procedure is also typically characterized by experimentally circumscribed sleep periods as a consequence of full schedules of psychological, psychophysiological and performance testing (see for example, Ryback & Lewis, 1971; Ryback, Lewis & Lessard, 1971).

One recently published study (Nakagawa, 1980) however, does provide some insight into sleep/waking cycles in the absence of cultural mediation and behavioral controls. In this study, subjects were required to remain lying quietly in bed for 10 to 12 hours immediately following a full night's sleep. The original aim of the study was to "elucidate changes in daytime states of consciousness" by observing "the EEG patterns of (awake) subjects in restrained postures under minimally changing experimental conditions" (p. 524). Despite explicit instructions to remain awake during the 10 to 12 hour period, however, subjects experienced "an uncontrollable desire to fall asleep," resulting in sleep/waking cycles of approximately 4 hours across the experimental period. Again, it appears that the uniphasic placement of the sleep process loosened in response to a reduction in behavioral controls.

In summary, most designs employed in the investigations of the human sleep/waking rhythm are inadequate for that purpose since they include strict controls over waking and sleeping as a necessary part of the procedure. However, results from studies in which such controls are relaxed indicate that subjects have a tendency to

relinquish their typical uniphasic sleep placement in favor of a more dispersed, polyphasic sleep system.

The present study attempted to address the hypothesis that behavioral, cultural and environmental factors serve to entrain an inherently ultradian sleep/waking rhythm to a uniphasic, 24-hour framework by imposing upon the organism a series of behavioral controls. In the experimental environment, such controls are frequently mimicked by circumscribed sleep/waking schedules, feeding regimens and testing procedures. These external controls "may create incompatible responses which suppress the expression of (the) rhythmic response or create such a 'noise' background as to not permit measurement" of the hypothesized ultradian rhythm (Webb, 1978 p. 315). Therefore, by minimizing "incompatible responses" and "noise background" the present study sought to "emancipate" the hypothesized ultradian rhythm from control by a self-imposed and/or sociophysical-mediated circadian framework. By so doing, it was proposed that the presence of such a rhythm may be more readily observed and measured. Specifically, subjects were required to maintain relatively static, basal levels of behavior over a period of almost three days, during which time their sleep/waking behavior was the primary variable of interest.

CHAPTER TWO METHODS

The subjects for this study were 10 young adults (5 males and 5 females) ranging in age from 18 to 25 years (mean = 20.4). Subjects were selected after questionnaire (Appendix 1) responses revealed normal sleep patterns and the absence of chronic health problems and/or acute illness.

Each subject slept for 2 nights in the laboratory immediately prior to the beginning of 60 consecutive hours of bedrest. Between the 2 nights in the laboratory subjects were permitted to maintain their normal daily schedules with the stipulation that no naps be taken and no drugs (including alcohol and caffeine) be ingested during that period.

For each session, 2 subjects reported to the laboratory approximately 1½ hours prior to their normal bedtimes (about 11 PM) for electrode placement. Five millimeter gold disc electrodes were applied over Cambridge electrode jelly and held in place by collodion saturated gauze strips. EEG and electrooculogram (EOG) were continuously monitored for each subject using a Grass Model VI electro-physiograph. The EEG of each subject was recorded on three channels between electrode sites Fp1 - F7, P1 - T5, and C3 - A2. The EOG was monitored on a separate channel by electrodes placed on the external canthus of each eye.

At the completion of electrode placement each subject retired to a private, electrically shielded, sound attenuated, temperature controlled room. Each subject's record was scored in one-minute epochs, following the methods described by Agnew and Webb (1972a). Cross-scoring of random 2-3 hour segments of the sleep portions of each record revealed a between-scorer reliability of greater than 90%.

Sleep onset was determined by the appearance of the first spindle or K-complex (Agnew & Webb, 1972b). A sleep period was considered as such when sleep continued, uninterrupted by more than 20 minutes of wakefulness, for at least 30 minutes. A waking period was defined as Stage 0 EEG for at least 20 minutes.

Timing of the 60 hours of bedrest began with the spontaneous awakening of each subject from his/her second night of laboratory sleep and the subject's verbal report that he or she felt rested and had had enough sleep. At this time subjects were given an opportunity to eat breakfast and use the bathroom. No intentional time cues were given the subjects upon awakening nor at any other time throughout the bedrest period, with the exception that each subject was told when he or she was "past the halfway point" at a random time after 30 hours had past. However, uncontrollable, general time cues from exogenous sources (eg., nearby building construction, general building noise during working hours, homecoming festivities during one session (subjects 945 & 946)) were present in varying degrees from session to session.

During the 60 hours of bedrest, subjects were allowed minimal exogenous stimulation. Activities such as reading, writing, listening

to music or watching television were prohibited. Conversations during the period were limited to brief dialogues with the experimenter at meal times. No instructions were given relative to when or when not to sleep. Subjects were asked to lie as quietly as possible, but were permitted to change positions in bed when inclined to do so. Closed circuit TV monitors were employed to insure adherence to the experimental instructions. Subjects were permitted to go to the bathroom (in room) at their convenience and were allowed to sit up in bed during meals.

Meals were served unsystematically (always during an ongoing waking period, as determined by the EEG) and consisted of a choice of several types of sandwiches, vegetable dishes, desserts and non-caffeinated beverages. A maximum of $\frac{1}{2}$ hour was permitted for the completion of each meal. Several types of fruit and a pitcher of ice water were also available to each subject ad libitum.

Illumination in each room was provided by a 60 watt lamp placed on a table by the subject's bed, and control of light and control of light and darkness was at the discretion of each subject.

CHAPTER THREE RESULTS

One of the 10 subjects terminated participation prior to the end of the bedrest period. Since only 12 hours of bedrest were recorded for this subject, the results presented here are those of the 9 subjects who completed the session.

The criterion used here to define a "sleep period" (i.e., 30 minutes of sleep, uninterrupted by more than 20 minutes of wakefulness) accounted for 91.3% of all sleep recorded. Eight sleep episodes had durations of less than 30 minutes (mean = 7.25 min., range = 2 to 18 min.), and therefore were not considered "sleep periods" in the following analyses.

Initial Sleep Period. The mean total sleep time (TST) for the sleep period immediately preceding the onset of the bedrest period (Night 2) was 8.72 hours, with a range of from 5.82 hours to 10.43 hours. Sleep stage percentages for the period were generally within normal limits. However, as shown in Table 1, there was a significantly greater proportion of Stage 0, t ($df = 39$) = 2.32, $p < .05$ (all levels of significance are based on a two-tailed test), and a smaller percentage of stage 1, $t(39) = 5.04$, $p < .001$, and stage 3, $t(39) = 2.20$, $p < .05$, in this sample as compared with a normative group of 16 males and 16 females of approximately the same age (mean = 24 years) previously recorded in the same laboratory (Williams, Agnew and Webb, 1964; 1966). "Chopping" each record to an artificial maximum

TABLE 1. - Comparisons of sleep stage characteristics for baseline (Night 2), bedrest period, and normative group.

	TST	%STG 0	%STG 1	%STG 2	%STG 3	%STG 4	%STG REM
** Normative (N=32)	7.52 h (.80)	.95 (1.35)	5.62 (3.74)	48.37 (7.02)	7.32 (3.25)	14.70 (5.30)	23.02 (3.71)
Night 2 (chopped')	7.61 h (.80)	2.54 (2.68)	1.63+++ (1.32)	52.55 (5.95)	5.97 (1.85)	14.72 (5.18)	22.41 (3.72)
Night 2	8.72 h (1.58)	2.99+ (2.54)	1.78+++ (1.14)	53.06 (6.52)	5.47+ (1.83)	13.42 (5.08)	23.55 (3.55)
Bedrest Period	27.99 h (5.39)	3.59++ (2.28)	3.28+ (1.87)	58.41+++ (4.94)	4.33+++ (1.24)	9.86++ (4.54)	20.47+ (2.94)

Mean
(SD)

significance levels (t test, two tailed): different from Normative -- + p < .05
++ p < .01
+++ p < .001

** from 2 studies by Williams et al. (1964, 1966)

of 8 hours for Night 2 (i.e., scoring no more than the first 460 minutes of each record) did not significantly change the mean proportions of sleep stages as compared to 'intact' Night 2, but such a procedure did reduce the proportions of stages 0 and 3 so that they were not significantly different relative to the normative group.

Bedrest Period. Although timing of the bedrest period (BP) began with the spontaneous awakening from Night 2 and the subject's acknowledgement that (s)he felt awake and rested, later analysis of the records of three subjects indicated that the 'spontaneous awakenings' were less than 20 minutes in length (7, 9, and 11 minutes) and were followed by substantial sleep episodes (mean = 2.11 hours). These episodes, therefore, were included in the initial sleep period (Night 2), and as a result, the bedrest periods of the 3 subjects were somewhat under 60 hours (mean = 55.32 hours). The mean duration of BP for the entire group was 58.8 hours (range = 53.1 to 62.2 hours).

Referring to Table 1 it can be seen that the sleep stage percentages averaged from sleep periods occurring during BP differed only slightly from those recorded during Night 2. There were non-significant increases in the proportions of stages 0, 1, and 2, while nonsignificant decreases in SWS and REM sleep were observed as compared to Night 2. Similar trends (all significant, however) were observed relative to the normative group, with the exception of stage 1, which comprised a smaller percentage of TST across BP than in the normative sample.

The distribution of sleep and wakefulness across BP, for all nine subjects, is presented in Figure 1. Figure 2 presents, in

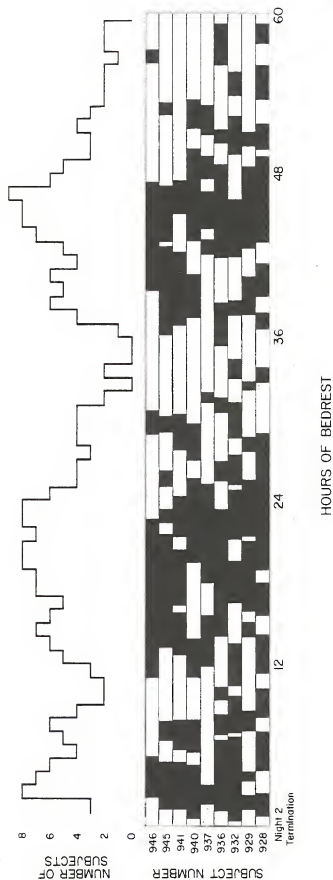


Figure 1. - Placement of sleep/waking episodes across 60 hours for individuals and group. Dark bars represent sleep periods.

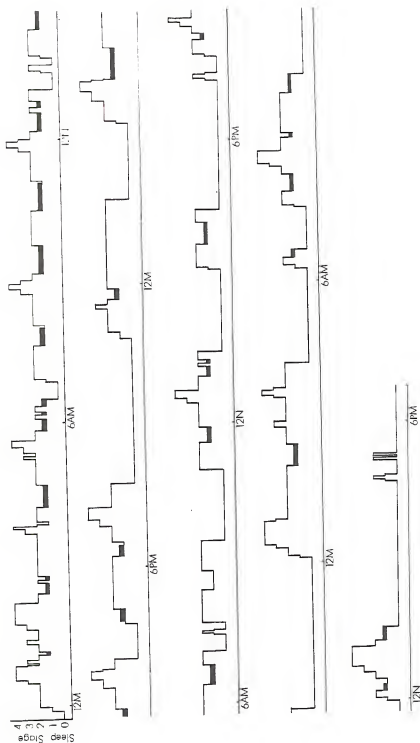


Figure 2. - Example of sleep staging across BP (subject 932). Awakenings of less than 20 minutes are not shown.

TABLE II. - Individual and group statistics for the bedrest period (BP).

Subject #	Bedrest Period	TST	Sleep Period Length	Sleep/Wake # Cycle Length	%Stg0	%Stg1	%Stg2	%Stg3	%Stg4	%REM
928	62.22h	37.31h	2.87h	13	2.09	5.34	60.72	3.83	3.74	24.25
929	60.23	23.87	2.17	11	4.17	3.41	63.92	4.38	8.56	15.52
932	60.14	33.12	2.76	12	4.02	2.06	63.75	3.06	6.98	20.11
936	60.37	32.30	3.23	10	8.23	5.76	52.88	5.56	10.81	16.93
937	60.57	19.92	2.49	8	3.67	4.68	53.59	4.93	9.61	23.32
940	60.27	28.40	3.55	8	1.76	3.70	60.28	3.17	9.69	21.38
941	53.08	25.28	3.16	8	1.57	.13	50.29	6.78	20.60	20.60
945	57.90	26.82	2.98	9	5.64	1.05	61.01	3.28	9.86	19.11
946	54.25	24.90	4.98	5	1.20	3.60	59.29	3.94	8.89	23.06
Mean	58.80	27.99	2.99	9.3	3.59	3.28	58.41	4.33	9.86	20.47
(SD)	(3.11)	(5.39)	(2.35)	(2.4)	2.28	(1.87)	(4.94)	(1.24)	(4.54)	(2.94)

TABLE III. - Distribution of bedrest sleep periods by the presence or absence of REM and Stage 4 sleep.

	Total #	Day	Night	Mean duration (range)	Time of occurrence
All stages present	59	36	23	3.75 hrs (.87 to 11.56 hrs)	
No stage 4	13	12	1	1.41 hrs (.5 to 2.9 hrs)	6:40am, 7:40am, 8:00am, 8:30am, 10:00am, 10:30am, 2:20pm, 3:10pm, 3:30pm, 4:30pm, 6:20pm, 9:00pm, 10:45pm
No stage REM	9	8	1	1.08 hrs (34 to 161 min)	2:40am, 10:20am, 2:05pm, 3:10pm, 4:00pm, 4:30pm, 6:05pm, 7:20pm, 9:55pm
Neither REM nor stage 4	3	3	0	1.02 hrs (38 to 85 min)	12:05pm, 2:40pm, 10:30pm

detail, the sequencing of sleep and wakefulness of one subject (932) across the bedrest period. Individual and group statistics for the entire bedrest period are presented in Table II. BP was characterized by an alternation of waking periods with an average length of 2.7 hours (range = .4 to 10.2 hours) and sleep periods with a mean duration of 2.99 hours (range = .5 to 11.6 hours). Subjects spent almost half of BP asleep (47.6%) with a mean total sleep time of 28 hours (range = 20 to 37.3 hours). Sleep was dispersed across an average of 9.3 episodes during the bedrest period (range = 5 to 13).

These results are in contrast to what would be expected under the assumption of a uniphasic model of sleep. Under such an assumption, one would predict 2 discrete sleep episodes across the 60 hours, placed within the normal nocturnal periods (approximately 11 PM to 7 AM), with a mean TST for the bedrest period of about 16 hours (about 27% of BP).

Sleep periods during BP could be divided into four general categories based on the presence or absence of stage 4 and REM sleep, as shown in Table III. Seventy percent (59) of all sleep periods recorded over the bedrest period were 'full blown' sleep episodes, in that all stages of sleep were observed. Of the remaining 25 sleep periods, 3 (all day episodes) showed neither REM nor stage 4 sleep. Nine sleep periods (8 days, 1 night) exhibited an absence of REM sleep and 13 (12 days, 1 night) showed no stage 4 sleep.

The mean period length of those episodes with neither REM nor stage 4 was 61 minutes. The mean duration of 'noREM' sleep periods was 65 minutes, and the 'noStg4' sleep episodes averaged 84 minutes

duration. This is compared to a mean duration of 225 minutes (3.75 h) for those sleep episodes which contained both stage 4 and REM.

The occurrence of these events in terms of sidereal time was also examined. The three periods containing no REM and no stage 4 occurred after noon and before the onset of the night phase (11 PM). All but 2 of the 'noREM' periods occurred between 2 PM and 10 PM. The 'noStg4' episodes occurred across the entire day phase (7 AM to 11 PM) with only one such episode occurring at 'night' (6:40 AM).

Regarding the mode of appearance of REM sleep episodes, of 153 REM periods recorded over BP, only 3 were characterized by onsets at the beginning of a sleep period. Sleep onset REM periods (SOREMPS) were defined as those REM episodes occurring at the onset of sleep which were not preceded by more than 1 minute of stage 2. Two sleep episodes containing SOREMPS also were characterized by the absence of stage 4 sleep. The SOREMPS were contributed by 3 subjects, had a mean duration of 15.3 minutes (9, 10, and 27 minutes), and occurred at approximately 6:30 AM, 6:30 PM, and 1:30 PM, respectively.

In an effort to further elucidate the factors involved in the cycling of REM sleep, two examinations were made. In the first procedure, the REM sleep cycle (defined as the interval between the onset of one REM period and the onset of the next) was calculated for each subject's baseline night (Night 2). The onset points of the cycle were then superimposed across each subject's entire bedrest period (including waking episodes) to test the hypothesis that the REM cycle was independent of prior sleep time. Also, the cycle was

superimposed across each subject's 'compressed' bedrest period, in which waking intervals were removed to obtain a continuous sleep period, to test the possible sleep dependency of the REM sleep cycle. The initial onset of the superimposed cycle corresponded to the onset of the last REM sleep period of Night 2.

The relationship between the superimposed REM cycle and the occurrence of actual REM episodes was examined by calculating the mean difference between each onset point of the hypothesized cycle and the closest REM epoch within that sleep period. The average difference between each onset of the superimposed cycle and the appearance of an actual REM epoch, across the intact bedrest period, was 15.8 minutes ($SD = 3.7$ min). The mean difference between the values for the 'compressed' BP was 14.5 minutes ($SD = 4.7$ min). The difference between the two conditions was not significant.

To further test the sleep dependency of the cycle, the mean REM cycle length of the 'compressed' BP, for the group, was determined. Again, beginning the cycle with the onset of the last REM period of Night 2, mean cycle length for the 'compressed' BP was 96.84 minutes ($SD = 10.42$ min). This is compared with a mean REM cycle length of 96.56 minutes ($SD = 12.76$ min) for Night 2.

Circadian Considerations. There were considerable differences in several measures as a function of time of day. For comparative purposes, waking and sleep periods were considered daytime events if they were initiated between 7 AM and 11 PM. Nighttime events were defined as those episodes with onsets between 11 PM and 7 AM.

TABLE IV. - Comparison of sleep variables as a function of night (11 PM - 7 AM) and day (7 AM - 11 PM).

	Overall	Night		Day
Mean TST	27.99 h (5.39)	15.34 h (3.30)		12.65 h (4.91)
Mean Sleep Period Length	2.99 h (2.35)	5.52 h (2.65)	**	1.93 h (.98)
Total # Sleep Episodes	84	25		59
Sleep/Wake Cycle Length	6.10 h (2.68)	7.81 h (3.26)	*	5.25 h (1.74)
% Stage 0	3.59 (2.28)	3.50 (2.26)		3.64 (3.58)
% Stage 1	3.28 (1.87)	3.88 (2.79)		2.81 (2.06)
% Stage 2	58.41 (4.94)	56.37 (5.76)		60.80 (6.22)
% Stage 3	4.33 (1.24)	4.13 (1.58)		4.94 (1.75)
% Stage 4	9.86 (4.54)	8.89 (5.37)		11.01 (4.28)
% Stage REM	20.47 (2.94)	23.13 (4.01)	**	17.54 (3.87)

Mean
(SD)

** p < .001 t test, two-tailed

* p < .01

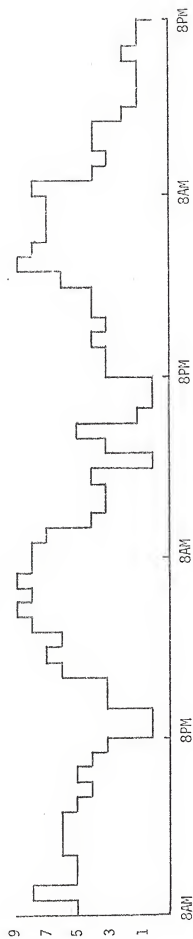


Figure 3.-Total number of subjects asleep, for each hour across the bedrest period.

Of 84 total sleep episodes recorded for the group across the bedrest period, 59 (70.2%) occurred during the day and 25 (29.8%) occurred at night. However, over half of the total sleep time (54.7%) during BP was obtained during episodes initiated between 11 PM and 7 AM.

Comparisons between day sleep periods (DS) and night sleep periods (NS) of temporal measures and sleep stage percentages are shown in Table IV. The most notable difference in measures of DS and NS was with regard to mean sleep period duration. NS episodes continued for a mean duration 5.52 hours (SD = 2.65 h) compared to an average length of 1.93 hours (SD = .98 h) for sleep episodes initiated during the day ($t(82) = 6.58, p < .001$). Conversely, the mean duration of waking episodes was 1.47 hours (SD = 1.04 h) for nighttime events and 3.12 hours (SD = 2.4 h) for those initiated during the day ($t(82) = 4.29, p < .001$). Consequently, the sleep/waking cycle length (defined as the interval between the onset of one sleep episode and the onset of the next) increased significantly from day (5.25 h, SD = 1.74) to night (7.81 h, SD = 3.26) $t(73) = 2.89, p < .01$.

Figure 3 presents, by hours, the number of subjects sleeping across the bedrest period. The group tendency toward nocturnal sleep placement is evident. Of 144 total subject-hours available for sleep during the 2 night periods (11 PM to 7 AM), 104 (72.3%) were used for that purpose. In contrast, of the 279 subject hours comprising the first and second day periods (8 AM to 11 PM and 7 AM to 11 PM) less than half (45.2%) were spent sleeping.

TABLE V. - Sleep onset times of longest sleep episodes for Nights 2 (baseline), 3, and 4.

Subject #	928	929	932	936	937	940	941	945	946	Mean
Night 2	11:48P	11:27	11:54	11:42	11:50	11:57	12:05A	12:15	12:18	11:55P
3	12:30A	12:34	3:30A	10:50	2:42	2:42	2:58	11:45	9:39	1:01A
4	12:07	2:54	12:04	2:15	4:33	2:28	11:30	11:21	2:14	1:43A

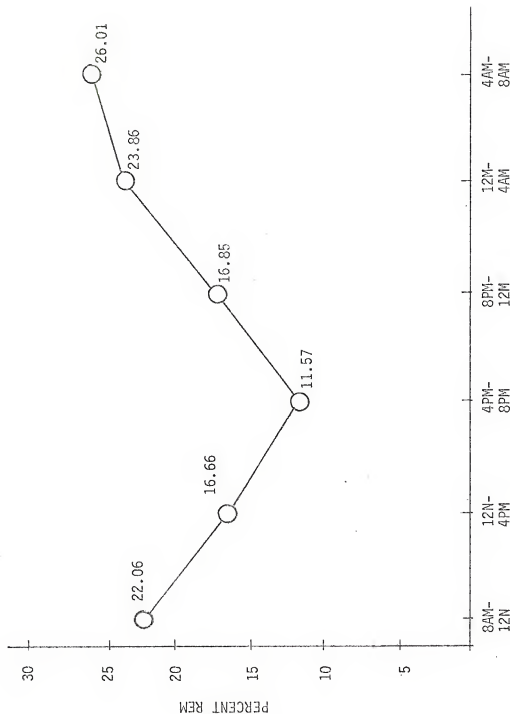


Figure 4.—Proportions of TST spent in REM sleep as a function of time of day. Percentages were obtained by dividing the total minutes of REM sleep for the group by total minutes of sleep, for each time block across BP.

The possible presence of a free-running sleep/wake rhythm was examined by comparing the mean sleep onset time of Night 2 (baseline) and the mean onset times of the longest sleep periods of Nights 3 and 4. The mean sleep onset times for the group exhibited a tendency to occur later on each succeeding night--slightly under 1 hour later on Night 3 (as compared to baseline) and 42 minutes later on Night 4 (as compared to Night 3). However, as shown in Table V only 2 subjects (929 and 937) demonstrated consistent free-running patterns across the three nights. Four additional subjects delayed the onset of their major nocturnal sleep onset on Night 4 (relative to Night 3).

Sleep stage percentages were not affected substantially as a function of time of day. While there was slightly less stage 1 (2.8 vs 3.9%) and slightly more stage 2 (60.8 vs 56.4%) and stage 4 (11 vs 8.9%) during the daytime sleep periods, only the difference in REM sleep percent was significant, with REM sleep comprising just over 23% of NS episodes and only 17.5% of DS periods ($t(82) = 5.91$, $p < .001$). The difference in REM percent appeared to be a consequence not only of the difference in sleep period length but also of the maintenance of a circadian pattern of REMS across the the bedrest period, as shown in Figure 4. The largest proportion of TST spent in REM sleep occurred during those sleep episodes initiated between 4 AM and 8 AM. The proportion of REM sleep decreased across the next three 4-hour time blocks until reaching a low of 11.57% of TST for sleep episodes initiated between 4 PM and 8 PM. The percentage of REM sleep then exhibited a steady increase across the subsequent 4-hour time blocks (8 PM to 12 MID and 12 M to 4 AM).

TABLE VI. - Comparison of sleep variables between first and second 24 hours of bedrest period.

	Overall	1st 24 HRS		2nd 24 HRS
Mean TST	27.99 h (5.39)	14.46 h (2.28)	**	10.97 h (2.36)
Mean Sleep Period Length	2.99 h (2.35)	3.54 (1.92)		2.82 h (1.44)
Total # Sleep Episodes	84	39		33
Sleep/Wake Cycle Length	6.10 h (2.68)	5.19 h (2.10)		5.64 h (2.04)
% Stage 0	3.59 (2.28)	2.94 (2.23)		4.48 (4.25)
% Stage 1	3.28 (1.87)	3.03 (1.93)		3.74 (2.66)
% Stage 2	58.41 (4.94)	59.69 (4.03)		56.68 (8.50)
% Stage 3	4.33 (1.24)	4.15 (1.40)		4.66 (1.58)
% Stage 4	9.86 (4.54)	8.39 (3.60)		11.39 (6.88)
% Stage REM	20.47 (2.94)	21.77 (2.56)		19.02 (4.82)
Mean (SD)	** p < .01 t test, two-tailed			

In addition to day/night differences, there was also disparity in temporal measures as a function of elapsed time within the bedrest period. Table VI compares TST, sleep period duration, sleep/waking cycle length, and sleep stage percentages recorded during the first 24 hours of bedrest with those recorded during the second 24 hours. Total sleep time for the first 24 hours (14.5 h) was significantly longer than TST for the second 24 hours (10.9 h) ($t(16) = 3.19$, $p < .01$). While the decrease in TST was, in part attributable to a reduction in the total number of sleep episodes during the second 24 hours (39 vs 33), a decline in the mean sleep period length across BP (3.54 h vs 2.82 h) also contributed to the difference.

Despite the decrease in overall sleep period duration, the sleep/waking cycle length remained essentially unchanged throughout the bedrest period. For purposes of comparison, only those sleep/waking cycles initiated and completed within one or the other 24 hour periods were considered. The mean duration of sleep/waking cycles occurring during the first 24 hours was 5.2 hours ($SD = 2.1$ h), while the mean cycle length of those completed during the second 24 hours was 5.6 hours ($SD = 2.4$ h).

There were no significant differences in sleep stage proportions between the 24-hour intervals. However, trends were observed relative to stages 4 and REM. Stage 4 increased (from 8.4 to 11.4%) from the first 24 hours to the next; this despite the fact that there were more sleep episodes containing stage 4 in the first 24 hours (32 vs 27). Conversely, REM sleep decreased by over 10% from the first to the second 24 hours.

CHAPTER FOUR DISCUSSION

The results of this study substantiate and further detail previous reports that a reduction in the control of the sleep response results in a 'loosening' of the uniphasic, nocturnally placed sleep pattern typically observed in adult humans. At the same time, however, the results underscore the tendency of sleep to be differentially weighted toward a definite and persistent nocturnal placement.

On the one hand, the data suggest a quadriphasic sleep pattern, with the onset of sleep episodes occurring at approximately 6 hour intervals throughout the bedrest period. While such a rhythmicity proved to be highly variable within subjects, from one sleep period to the next, the relatively small between-subjects variability emphasizes the regularity of such a rhythm within the group. That the number of sleep periods was proportionately placed, relative to day and night, further accentuates the uniform distribution of sleep episodes across the 24-hour day. The 'day' phase (7 AM to 11 PM) comprised approximately 73% of the total bedrest period. Correspondingly, 70% (59) of the total number of sleep episodes recorded across BP were initiated during the day.

On the other hand, comparison of the mean duration of those day sleep periods with the average length of sleep periods initiated at night clearly illustrates the substantial orientation toward the

nocturnal placement of total sleep time. Over half (55%) of the total sleep time recorded during BP was obtained during sleep periods initiated between 11PM and 7AM, despite the fact that 'night' comprised only 27% of the total bedrest period.

These findings are in accord with those reported by Weitzman et al. (1974) relative to the placement of the sleep of subjects maintained on a 3-hour 'day'. In that study, the sleep of 7 subjects exhibited a strong tendency to occur during the scheduled sleep periods beginning at 3AM, 6AM, 9AM, and noon. While the authors note the shift away from typical sleep placement (i.e., 11PM - 7AM) during the 10 days of ultradian cycling, they emphasize the "highly resistant nature" of the circadian loading of the sleep response.

Webb and Agnew (1974a) also noted a tendency for subjects to maintain a circadian, primarily nocturnal, placement of total sleep time in a free-running environment. The authors cite three aspects of their findings which suggest a continuation of "the entrained influence of the original 24-hour cycle." First, several subjects showed sleep onset times during the first 3 or 4 days which were significantly earlier than would be predicted by a pure free-running hypothesis. Secondly, throughout the 14 days of the study, there were tendencies on the parts of 5 of the 7 subjects for sleep onset times to 'regress' periodically, thereby increasing the probability that sleep onset would occur during the nocturnal phase (between midnight and 7AM). Finally, there were two occasions in which subjects skipped sleep periods, the predicted onsets of which would have occurred during the day phase (specifically, noon and 4PM), and instead delayed initiation of the next sleep periods to nocturnal placements (11PM and 3AM, respectively).

The tendency toward a free-running sleep/waking cycle was not apparent in the present study. While the mean sleep onset times of the major nocturnal sleep episodes became successively later across the three nights, only 2 individuals exhibited such a tendency. Other subjects delayed sleep onset on Night 3, only to advance onset time on Night 4. Still others exhibited a reverse trend. Such 'scalloping' of the expected free-running rhythm in the present study may reflect the continued inclination of some subjects to maintain their sleep in its typical nocturnal placement.

Total Sleep Time. The results of the present study are also consistent with previous findings relative to the amount of total sleep obtained. In summing up the findings on studies of unrestricted sleep, Webb and Agnew (1975a) noted that "it may now be stated with confidence that permitting subjects to sleep ad lib under conditions which have not increased the sleep need by prior deprivation or increased energy expenditure will consistently result in increased sleep length," (p. 369). In addition, sleep logs maintained across several weeks reveal that average weekday ('restricted') sleep and weekend ('unrestricted') sleep differs by an hour or more (Johns, Gay, Goodyear, and Masterton, 1971; Webb, 1981; White, 1975).

The subjects in the present study were instructed, on Night 2, to sleep until they felt well-rested and no longer sleepy. The mean sleep duration for Night 2 (8.7 hrs) was within minutes of the mean total sleep time (8.8 hrs) reported for 4 subjects (10 nights each) permitted to sleep as long as they wished, following 10 nights of 'restricted' sleep which averaged 7.4 hrs per night (Webb and Agnew,

1974a). The mean sleep length for Night 2 is also in agreement with self-reported extensions in weekend sleep lengths (about 8.5 hrs).

The mean total sleep time reported here is, however, almost an hour less than that of young adults (9.6 hrs) studied by Verdone (1968) and Webb and Agnew (1975a). It seems likely that the mean total sleep time for Night 2, like typically reported weekend sleep, was a consequence of the relaxation of self-imposed controls on sleep length (e.g., alarm clocks), rather than an expression of the complete satisfaction of sleep 'need'. Several subjects in the present study were rather impatient to terminate Night 2 and to initiate the bedrest period. This is illustrated by the case of one subject who reported, during a brief (3 min) awakening, that she felt rested and had "had enough sleep." The report came after approximately 2 hours had elapsed in Night 2. Clearly, such eagerness to 'get on with it' may have resulted in the termination of sleep prior to the spontaneous ending of sleep due to satiety.

A more accurate measure of maximum sleep length may be derived from the examination, across the bedrest period, of sleep durations per 24 hours. Beginning with the termination of Night 2 (typically around 8AM) the first 24-hour period was characterized by an average of 14.5 hours of sleep, the second 24 hours contained an average of almost 11 hours of sleep. Such figures are consistent with previously reported 24-hour sleep amounts. For example, Aserinsky (1969) instructed subjects to "make every attempt to sleep" while confined to bed for 30 hours (interrupted only twice for meals). During the first 24 hours (midnight to midnight) subjects obtained an average of 14.4 hours of sleep. During the 24-hour period beginning at 7:30AM, after a full

night's sleep (mean = 7.04 hrs.), the mean sleep duration was 12.98 hrs. This figure is in remarkable agreement with the average TST for each of the first 2 24-hour periods, subsequent to Night 2, in the present study (12.71 hrs.). In light of such findings, it appears that 12 to 13 hours of sleep per 24 hours may be considered a close approximation of the maximum capacity for sleep (Aserinsky, 1969). However, at least three lines of evidence suggest that substantially shorter sleep times may represent the maximum point of sleep "need". First, it has been proposed that REM density may be a reflection of "satisfaction of a sleep need, or . . . the buildup of a pressure to awaken" (Aserinsky, 1969, p. 155). It was found in that study that REM density reached maximum values after 7.5 to 10 hours of sleep. Secondly, under conditions of perceptual deprivation, subjects averaged about 12 hours of sleep during the first 24 hours, but subsequently reduced sleep lengths until they approached baseline levels (about 7.5 hrs.) by the third or fourth day of deprivation (Potter and Heron, 1972). Also in the present study, total sleep time during the second 24 hours of bedrest decreased almost 25% when compared with that of the first 24 hours. It might be speculated that the decline would have continued, if bedrest had continued.

Nevertheless, with the exception of the perceptual deprivation study cited above, all values of sleep satiation or fulfillment of sleep "need" substantially exceed the 7- to 8-hour sleep durations typically reported for normal young adults. The interpretation of such findings may be generally separated into two opposing views. It has been suggested, on the one hand, that the extended sleep observed in unrestricted sleep regimens is a consequence of decreased sensory input (see for example, Nakagawa, 1980; Heron, 1957). Proponents of

this view have speculated that an important function of the sensory and perceptual systems is to maintain a waking level of arousal in the reticular activating system. In studies comparable to the present one, where conditions are maintained at a relatively constant level, and sensory stimulation is not only static but also depressed relative to normal levels, input from peripheral afferent pathways may be insufficient to furnish the appropriate level of RAS activation. "In general, appropriate sensory stimulation is needed to maintain an arousal state in animals, but repetitive monotonous stimulation habituates the arousal reaction . . .," (Nakagawa, 1980, p. 532). In short the, according to this view, extended sleep is the result of neurological "boredom" and/or habituation. Implied in such a view is the notion that the extended sleep time observed under unrestricted or bedrest conditions is not representative of natural sleep tendency (or requirement), but rather, is simply one consequence of the organism's decreased requirement to process environmental stimuli and respond accordingly (Heron, 1957).

This is analagous to Flanigan's (1971) suggestion that the extended sleep observed in nonhuman subjects maintained under controlled and highly favorable conditions (i.e., limited activity, plenty of food, no predators) may reflect the upper limits of sleep that are organismically possible, rather than that which is typical in the animal's natural habitats.

In contrast, it has been suggested (see for example Webb and Agnew, 1975a) that the extended sleep lengths characteristic of unrestricted sleep conditions are, in fact, "normal" and that typically reported sleep durations of 7 to 8 hours may actually be the product of chronic sleep deprivation. In support of such a notion is the finding that

only one third of a group of individuals who completed 6-month sleep diaries reported that they usually awakened spontaneously in the morning. Further, half of the respondents in the study reported that they were typically not well-rested upon awakening (Kleitman, Mullin, Cooperman, and Titelbaum, 1937). The extension of sleep on weekends reported by most individuals also suggests a 'need' for more than the typically obtained weekday mean. Further, it has been shown that after 3 consecutive nights of sleep, restricted to a period between 11PM and 7AM (mean = 7.5 hrs), subjects slept an average of 2 hours longer on the 4th night when allowed to awaken spontaneously (Webb and Agnew, 1975a). The subjects in that study were not encouraged to extend sleep; indeed, they were "unaware that they would be allowed to sleep longer."

Similarly, the subjects in the present study were given no instructions relative to the maintenance of sleep and wakefulness during the bedrest period, yet they also obtained substantially more sleep than self-reported normal sleep durations. This seems to be suggestive of an inclination toward, if not an actual 'need' for, more sleep than is typically obtained. Of interest is the observation that the extended sleep durations resulted not from a lengthening of sleep episodes initiated at night, but rather from the addition of day sleep periods. Nocturnal sleep (11PM to 7AM) per 24 hours did not exceed normal night sleep (7.8 h). However, day sleep episodes contributed an average of approximately 5 hours to each 24-hour total. It might be speculated that the usual sacrifice of such day sleep periods is the source of our chronic sleep deprivation. On the other hand, the bedrest environment in the present study was highly monotonous, with novel sensory input severely curtailed. It is, therefore, likely that such conditions

contributed somewhat to the observed tendency for extended sleep times, as well.

Intrasleep Structure. The mean sleep stage proportions of the combined sleep periods during BP did not differ significantly from those of the baseline night (Night 2), and were within normal limits reported for young adult populations, although REM and slow wave sleep (SWS) were significantly reduced when compared to the normative sample used here. Such findings are in agreement with those reported by Webb and Agnew (1977) relative to the distribution of sleep stages in experimentally controlled, polyphasic sleep regimens. That is, despite influences from changes in sleep length, prior wakefulness and sleep onset times associated with various schedules of dispersed sleep, "when the total sleep obtained during these altered regimens is compared with baseline sleep on a 24-hour regimen, the basic structure of sleep persists" (p. 448).

Also, in accord with previous reports of dispersed and nap sleep (Maron, Rechtschaffen and Wolpert, 1964; Moses, Hord, Lubin, Johnson, and Naitoh, 1975; Nakagawa, 1980; Webb and Agnew, 1977; Weitzman et al., 1974) the occurrence of REM sleep maintained a circadian pattern across the bedrest period. Sixty percent of total REM time occurred during sleep episodes initiated between 11PM and 7AM. Further, while only 9 of the 84 sleep periods recorded during BP contained no REM sleep, 8 of those sleep episodes occurred during the day, and 7 occurred between 2PM and 10PM. Finally, Figure 4 graphically points out the tendency of REM sleep to occur differentially at intervals across the 24-hour day, with maxima and minima of the circadian oscillation occurring between 4 and 8AM and 4 and 8PM, respectively. Such data seem to underscore the tendency for REM sleep to occur differentially across the 24 hours.

The decrease in REM percent during the bedrest period, compared to baseline, also appears to have been the consequence of the circadian placement of REM sleep. While total REM time was differentially obtained within a relatively circumscribed time block, total sleep time was influenced somewhat less by such contingencies. In addition, opportunities for day sleep, when REM was less likely to occur, occupied a larger percentage of the bedrest period than did night sleep time. As a result, over the bedrest period, absolute sleep time was augmented to a greater extent than was REM time, thereby lessening the proportion of TST spent in REM sleep.

The decreased proportion of REM sleep recorded over the bedrest period may also be attributable, in part, to the decrease in mean sleep period length, relative to baseline, associated with BP. It has been shown that the amount of TST spent in REM sleep becomes proportionately less with the reduction of sleep length (Webb and Agnew, 1977). Since mean sleep period length during the bedrest period was almost two-thirds less than that for the baseline night (2.99 hrs. vs 8.75 hrs.), a corresponding decline in the proportion of REM sleep for the majority of sleep periods during BP would also be expected.

The observed decrease in REM percent, however, may also be a reflection of the decreased mobility and/or lack of novel perceptual stimulation characteristic of the bedrest situation. Several investigations of sleep patterns during prolonged bedrest have reported similar declines in REM sleep (Aserinsky, 1969; Nakagawa, 1980; Ryback and Lewis, 1971). In addition, Adey, Bors and Porter (1968) reported decreased proportions of REM sleep in quadriplegic patients, relative to normal amounts. The authors proposed that the diminished REM sleep was related

to "loss of most motor performance in the waking state," as well as the "absence of highly focused attention in complex motor activity." The finding by Ryback and Lewis (1971), that subjects who were permitted no exercise while confined to bed exhibited decreased REM sleep, while those who were allowed to exercise during bedrest did not exhibit such a decline, also provides some support for this notion. In the present study, the finding that REMS percent decreased (albeit slightly) from the first to the second 24 hours, may likewise be interpreted as supporting an immobilization/sensory habituation effect on the amount of REM sleep obtained.

A rather unexpected finding in the present study was that of an increase (though not significant) in the proportion of SWS, as the bedrest period progressed. In their examination of patients with high cervical lesions, Adey et al. (1968), reported the diminution of SWS as well as decreased REM percentage. As with REM sleep, the authors concluded that such a decline was the consequence of immobility. Thus, the findings of the present study appear contrary to what would be expected by an immobilization hypothesis.

On the other hand, the results reported here are in accord with the findings relative to SWS reported by Ryback and Lewis (1971). The bedrest subjects in that study exhibited increases in SWS with the nonexercise group showing the larger rise. These results were interpreted by the authors as indicating that SWS may serve to "repair or maintain the muscular system" in response to the effects of atrophy, as well as hypertrophy. Thus, it would appear that a change in the proportion of SWS, in either direction, may be explained by one or the other version of an immobilization hypothesis.

However, it seems somewhat unparsimonious to have to employ both versions to satisfactorily explain the data in terms of immobilization. In the present study, SWS comprised a smaller proportion of TST during BP than during the baseline night. The hypothesis proposed by Adey et al. is useful in explaining such results. Yet, within the bedrest period, there was an increase in the percentage of SWS from the first to the second 24 hours. These findings clearly require the Ryback and Lewis version.

Several observations seem to support an alternative explanation for the increase in SWS across the bedrest period, however. It has been shown (webb and Agnew. 1971, p. 1354) that "longer periods of wakefulness before sleep result in greater amounts of stage 4 sleep in the first 3 hours of sleep." In the present study, the mean interval between sleep episodes increased by some 70% (from 1.65 hrs. to 2.82 hrs.) from the first to the second 24-hour period. At the same time, the proportion of SWS increased almost 25% (from 12.9% to 16%). By the same token, periods of wakefulness between sleep episodes averaged about 1 hour longer during the day than at night (3.32 hrs. vs 2.29 hrs.). Correspondingly, SWS comprised a slightly greater proportion of day sleep than of night sleep episodes (16.2% vs 13.2%). The relationship between prior wakefulness and subsequent amounts of SWS seems apparent.

Such an association would also account for the decline of SWS from Night 2 to the bedrest period. The amount of wakefulness preceeding the baseline night (14 to 17 hrs.) far exceeded the duration of waking intervals characteristic of BP. Consequently, the subsequent sleep periods reflected this difference by exhibiting differential

proportions of SWS sleep. Inconsistent with a prior wakefulness hypothesis, however, is the observation by several investigators that there is a SWS 'kick' in the records of extended sleep. That is, extended sleep is often characterized by the reappearance of substantial SWS episodes in the late morning. The possible significance of such a finding is considered later in the discussion.

Results of the examination of the influence of prior sleep on the REM sleep cycle are best described as equivocal. Two examinations were made, one to test the notion that the REM cycle is sleep-dependent, the other to examine the possibility that the REM cycle is, instead, a sleep-independent rhythm based on elapsed clock time, regardless of state. Support for both views may be found in the literature. For example, Globus (1966) found that the cycling of REM sleep demonstrated "at least in part" a tendency to be a time-locked, rather than a sleep-dependent, rhythm in the nap sleep of 2 subjects recorded for a total of 107 REM periods. This conclusion was based primarily on the observation that correlations between sleep onset and REM onset decreased at certain times in the afternoon (between noon and 3 PM). That is, during this interval sleep onset got progressively later while REM onset remained constant relative to real time. Yet, prior sleep was not considered and, therefore, the interpretation of such findings is problematic.

In contrast, Moses et al. (1975) and Moses, Lubin, Johnson, and Naitoh (1977) reported findings which suggest that the REM sleep cycle is a sleep-dependent phenomenon. In the 1977 study, the nap sleep of 25 subjects was 'compressed,' by subtracting all intervening waking periods, and then examined as a single sleep episode. The resulting mean REM cycle lengths did not differ significantly from those recorded

during baseline sleep. The same procedure was carried out in the present study, and similar results were obtained. Using the onset of the last REM period of Night 2 as a starting point, the mean REM cycle length was determined for subjects' 'compressed' bedrest periods, and compared to the mean cycle length for Night 2. The mean cycle length for the compressed period differed from the cycle length for Night 2 by less than 1 minute (96.84 min vs 96.56 min). Such evidence is strongly suggestive of a sleep-dependent cycle.

In a second test, each subject's mean REM cycle length for Night 2 was superimposed on both his/her 'intact' bedrest period (i.e., including waking periods) and 'compressed' bedrest period. The mean deviation of an actual REM occurrence, from the onset of the hypothesized cycle, was used as a measure of 'goodness of fit.' The mean deviation across the 'compressed' bedrest period was 14.5 minutes. In other words, the actual occurrence of REM periods during BP differed by an average of about 15 minutes, as compared to expected occurrences, when intervening waking episodes were disregarded. Again, such a finding is supportive of a sleep-dependent REM sleep cycle. However, a similar finding that the mean deviation of actual REM sleep from hypothesized REM periods across the 'intact' bedrest period (15.8 min), precludes the acceptance of the sleep-dependence of REM sleep at the absolute exclusion of the 'real time' model.

Numerous studies of napping and dispersed sleep (Carskadon and Dement, 1975; Globus, 1966; Moses et al., 1975; Nakagawa, 1980; Webb et al., 1966) have reported perturbations in the mode of appearance of REM sleep episodes, characterized by the onset of REM sleep within minutes of the initiation of a sleep period. The reported frequencies

of occurrence of such sleep onset REM periods (SOREMPs) have ranged from as few as 3 out of 107 REM episodes (Globus, 1966) to as many as 21 of 34 REM episodes (Moses et al., 1975). Maron et al. (1964) reported the occurrence of no REM onset periods in the examination of 18 subjects who napped in either the afternoon (about 1:30PM) or evening (about 7:30PM). Yet, the overall rate of occurrence of SOREMPs for 5 studies of dispersed and nap sleep (Carskadon and Dement, 1975; Globus, 1966; Moses et al., 1975; Nakagawa, 1980; Weitzman et al., 1974) is rather substantial at 39% of all REM periods recorded (range 2.8% - 72%). Since such events are almost never observed in normal nocturnal sleep, SOREMPs have been considered to be indications of the overall disruption of normal sleep structure associated with day sleep episodes and dispersed sleep regimens (Weitzman et al., 1974; Moses et al., 1975).

In the present study, of 153 REM episodes recorded over the bedrest period, only 3 were initiated at the beginning of a sleep period (i.e., before the appearance of 2 min of stage 2). The infrequency of such occurrences suggests that the dispersed sleep of the present study may be of a different sort than typically observed nap sleep or experimentally dispersed sleep.

Such a view is further supported by the regularity with which sleep stages occurred across the bedrest period. Seventy percent of all sleep periods recorded during BP were 'full blown' sleep episodes (61% of day sleep episodes); that is, all sleep stages were present. By comparison, only 16% of the 560 opportunities for sleep in the Weitzman et al. study contained all stages. Of the 80 naps examined by Moses et al. (1975), 27.5% contained both SWS and REM sleep. REM sleep occurred in 90% of all sleep episodes during BP (86% of day sleep episodes), SWS occurred

in 85% of the sleep periods in this study (80% of day sleep periods). Again by comparison, the naps of subjects studied by Moses et al. contained REM episodes 43% of the time; 35% of the sleep opportunities examined by Weitzman et al. contained REM and 48% contained SWS.

Seven of the 9 sleep periods which contained no REM sleep occurred between 2PM and 10PM. Such a finding is consistent with previous ones that REM sleep typically increases in amount from midnight to morning and decreases toward evening (Moses et al., 1975; Nakagawa, 1980; Weitzman et al., 1974). It is likely, then, that the absence of REM during some sleep episodes in the present study were, at least in part, due to circadian effects.

A similar possibility also exists relative to 'missing' periods of SWS (specifically, stage 4). Several examinations of extended sleep (see for example, Gagnon and Dekoninck, 1981; Webb, Campbell and Hendlin, 1981) have noted the re-occurrence of stage 4 (in relatively large amounts) during the late morning. In the present study, sleep episodes characterized by the absence of stage 4 occurred across the entire day (6:40AM to 10:45 PM). It is interesting to note, however, that an obvious 'gap' occurred between 10:30AM and 2:20PM. That is, the sleep episodes initiated during those four hours always contained stage 4 sleep. Sleep periods initiated after about 11PM, and throughout the night, also contained stage 4. Thus, it might be suggested that the absence of stage 4 in 15% of the sleep episodes in this study, was the manifestation of the biphasic cycling of stage 4 sleep, rather than a reflection of the disruption of normal sleep processes. A further indication of the possible bipolar nature of stage 4 is the observation that total stage 4 time for BP was evenly distributed between day and night (716 min vs 714 min).

Clearly, the differences in the appearance and sequencing of sleep stages between this study and the 2 studies of nap sleep with which it has just been compared, are attributable in large part to the difference in mean sleep episode length (3 hrs. vs 1 hr.). This is especially true of REM sleep, if sleep dependency is assumed. Nevertheless, the persistence and regularity with which sleep stages occurred across the bedrest period is noteworthy. There were no significant differences in the proportions of sleep stages between bedrest sleep and Night 2 sleep. Nor, were there significant changes in sleep stage percentages between the first and second 24 hours of bedrest. Finally, only REM sleep percent varied significantly relative to day or night onset times.

Weitzman et al. (1974) noted that the sleep episodes which they observed were "clearly not minatures of the normal 8 hr. sleep pattern." Such a view has been echoed by most others who have studied dispersed sleep and naps. Most of these studies have differed from the present one, in that the sleep periods were typically experimentally circumscribed, rather than being placed on a 'self-demand' schedule. Such a methodological difference may account for the dissimilarity of results reported here.

Yet, Nakagawa (1980) also reported significant differences in day episodes versus baseline (night) sleep, despite the fact that the onset and termination of sleep periods was not regulated. Significant increases in stage 1, significant decreases in stages 4 and REM and the presence of SOREMPs led Nakagawa to conclude that "daytime sleep itself might be characterized as a special sleep at the onset of the diurnal sleep-waking cycle," (p. 534).

In that study, Nakagawa noted a sleep/waking cycle of approximately 4 hours, and suggested that a significant relationship seemed to exist between this cycle and the scheduling of meals. The quadriphasic rhythm observed during the present study did not appear to be the result of feeding schedules, since less than half (42%) of waking periods were used for meals. Further, one subject (#932) fasted for the duration of the experiment, yet maintained the least variable sleep/waking cycle of the group.

Uniphasic or Ultradian? The results of the present study seem to suggest, then, that the daytime sleep observed was not a "special" sleep, but rather was the continuation of an ultradian sleep/waking rhythm, which nevertheless maintained a definite tendency to be weighted toward a nocturnal placement, relative to total sleep time.

The regularity with which sleep episodes were initiated across the bedrest period also seems to support the notion of an ultradian pattern of sleep. The mean within-subject variability of the sleep/waking cycles was 2.66 h (=SD). While the between-subject variability was similar (SD = 2.73), most of the variability was contributed by a single subject. This subject (#946, see Table II) exhibited a sleep/waking cycle (13.59 h) which more than doubled the mean sleep/waking cycle length of the other 8 subjects (5.85 h). Likewise, the variability of the sleep/waking cycle of this subject (SD = 4.52) exceeded the group mean by almost twice (SD = 2.43). Excluding this subject's sleep/waking cycle length from the group mean reduces the variability of the quadriphasic rhythm to less than an hour (SD = 57 min).

Such a pattern of variability is similar to that observed for the REM sleep cycle. The 90 to 100 minute REM cycle is of limited value in predicting the occurrence of REM episodes within the sleep record of a single subject. Yet for a population, the predictability of a 90-100 minute cycle is quite good.

A further indication of the regularity of the quadriphasic sleep/waking cycle is the observation that the overall cycle length did not change significantly from one 24 hour period to the next. On the other hand, the length of the sleep/waking cycle did differ as a function of day and night, with the night cycle being substantially longer (7.8 hrs. vs 5.2 hrs.). It might be speculated that this difference was the consequence of subjects having spent the majority of their lives entrained to a monophasic sleep system, and that given time, the difference in cycle lengths might diminish. The present data do not support such a notion, however since the difference between night sleep/waking cycle length and day sleep/waking cycle length did not lessen significantly in the second 24 hours of bed-rest.

The polyphasic distribution of the sleep of numerous animals under experimental conditions is well documented. Berger (1972) has noted that "if we wish to study comparative aspects of normal sleep, we shouldn't impose wakefulness at any time on any species, including the human, but should take 24-hour recordings under equivalent conditions." The relatively basal activity levels, absence of novel perceptual stimulation and the satisfaction of bodily functions characteristic of the present experimental situation are comparable

to typical conditions under which animal sleep is studied. That a polyphasic sleep pattern was exhibited under such conditions, therefore, was not completely unexpected. Indeed, in 1972 Snyder speculated that "even in the human we would probably find polyphasic sleep if we used the same conditions that we use for animals," (p. 45).

While the monotony of the situation was quite likely instrumental in the increase in total sleep time over the bedrest period, it seems less probable that such "neurological boredom" would be expressed in a cyclic manner. Yet, the possibility remains, as noted by Weitzman (1972) with regard to the sleep cycle in cats. "In your experimental situation, . . . you are measuring in part the shift of pattern which is taking place from a previous long-established light-dark pattern, in addition to adaptation to a strange new environment. Are you measuring the effect of that shift as well as the intrinsic rhythmicity in the cat? If the measured rhythmicity were constant over, say, several weeks, then it would support the concept that a basic rhythmicity was being measured. However, if it tended to change over 1, 2, or 3 weeks that would suggest that you are at least partially measuring an adaptation effect," (p. 201). Obviously, the question relative to human sleep cannot be resolved by results of the present experiment.

It is suggested, though, that the conditions of the present study represented a further advancement along a continuum of slackened behavioral controls over the sleep process, the results of which was a clearer manifestation of an inherent ultradian sleep/waking rhythm, rather than the adaptation of the sleep response to a "strange new environment." It is further suggested that such a rhythm, albeit in

highly dampened form, may also be reflected in the occasional naps taken by normal adults (especially on weekends), the increased frequency of naps associated with the loosened schedules of geriatric and college populations, the sleep patterns of infants, and the polyphasic sleep patterning noted in unstructured environments (i.e., Arctic expeditions).

And, I would suggest one additional manifestation of the ultradian nature of the sleep response. Webb (1969) has noted that "(no one yet has exploited a foundation to study the 'siesta' patterns of the tropical and subtropical cultures, although at various odd moments, I am most tempted)," (p. 58). Results of the present study may suggest that such a proposal, to examine cross-cultural diversity in the cycling of rest and activity, may deserve a better fate than parenthetical consideration.

APPENDIX 1 SLEEP QUESTIONNAIRE

1. How many hours, on the average, do you usually sleep per night?
less, 5, 5½, 6, 6½, 7, 7½, 8, 8½, 9, 9½, 10, more
2. How many hours of sleep per night do you think that you need to feel well and function adequately? _____
3. How many hours of sleep per night do you prefer to have when you have a chance?
4. In general, the amount of sleep that you usually get is:
not enough about enough too much
5. On the average, about how many naps do you usually take each week?
0, 1, 2, 3, 4, 5, 6, 7, 8, or more
6. About how many total hours do you usually spend each week taking naps? _____
7. About how many times on the average do you wake up each night?
0, 1, 2, 3, 4, 5, 6, 7, 8, or more
8. About how much total time do you spend awake after going to sleep?
none, less than 5 min., 5-15, 16-30, 31-60, more _____
9. About how many minutes does it typically take for you to go to sleep? less than 5, 5-15, 16-30, 31-60, more than 1 hour

10. How often do you have trouble getting to sleep as quickly as you would like? Almost never, occasionally, often, almost always
11. How much do you enjoy sleep?
not at all, a little, moderately, much
12. How regular are your bedtimes?
very regular, somewhat regular, somewhat irregular, very irregular
13. How regular are your wake-up times?
very regular, somewhat regular, somewhat irregular, very irregular
14. What is your average bedtime during weekdays? _____
(to nearest 15 min.)

15. What is your average bedtime on weekends? _____
(to nearest 15 min.)
16. What is your average wake up time on weekdays? _____
(to nearest 15 min.)
17. What is your average wake up time on weekends? _____
(to nearest 15 min.)
18. How well do you usually sleep at night?
Very well, satisfactorily, some problems, poorly.
19. Do you usually feel well rested when you wake up, or soon thereafter?
Almost never, occasionally, often, almost always
20. On the average, how many days per week do you usually go to bed more than one (1) hour earlier or later than your average bedtime?
0, 1, 2, 3, 4, 5, 6, 7
21. On the average, how many days per week do you usually wake up more than one (1) hour earlier or later than your usual wake up time?
0, 1, 2, 3, 4, 5, 6, 7
22. Do you consider your sleep very light or very deep? Check below.
very light _____ very deep
23. Do you feel tired during the day because you have slept poorly?
Never sometimes often always
24. How much alcohol do you drink?
Never sometimes everyday
25. Do you wake up before you intend to?
_____ never
_____ once or twice a month
_____ once or twice a week
_____ nearly every day
26. Do you use sleeping pills to get to sleep?
_____ never
_____ about once a month
_____ about once a week
_____ nearly nightly
27. What, if any, sleeping pills do you use?
28. What, if any, prescription drugs are you presently taking?

REFERENCES

- Adey, W., Bors, E. and Porter, R. EEG Sleep Patterns After High Cervical Lesions in Man. Arch. Neurol., 1968, 19, 377-383.
- Agnew, H. and Webb, W. Sleep Stage Scoring. J. Suppl. Abstr. Serv., Am. Psychol. Assoc., Ms., 1972a, No. 293.
- Agnew, H. and Webb, W. Measurement of Sleep Onset by EEG Criteria. Amer. J. EEG Technol., 1972b, 12(3), 127-134.
- Aschoff, J. Circadian Rhythms in Man. Science, 1965, 148, 1427-1432.
- Aschoff, J. Features of Circadian Rhythms Relevant for the Design of Shift Schedules. Ergonomics, 1978, 21(10), 739-754.
- Aschoff, J. and Wever, R. Human Circadian Rhythms: A Multi-oscillatory System. Federation Proceedings, 1976, 35(12), 2326-2332.
- Aserinsky, E. The Maximal Capacity for Sleep: Rapid Eye Movement Density as an Index of Sleep Satiety. Biological Psychiatry, 1969, 1, 147-159.
- Berger, R. Discussion in Chase, M. H. The Sleeping Brain, Perspectives in the Brain Sciences, Brain Information Service/Brain Research Institute, Vol. 1, p. 45, Los Angeles: UCLA, 1972.
- Carskadon, M. and Dement, W. Sleep Studies on a 90-minute Day. Electroenceph Clin. Neurophysiol., 1975, 39, 145-155.
- Colquhoun, W. P. Circadian Variations in Mental Efficiency. In W. Colquhoun (Ed.), Biological Rhythms and Human Performance, pp. 39-107, New York: Academic Press, 1971.
- Ellingson, R. Ontogenesis of Sleep in the Human. In G. Lairy and P. Salzarulo (Eds.), The Experimental Study of Human Sleep: Methodological Problems, pp. 129-150, New York: Elsevier Pub., 1975.
- Flanigan, W. Phylogeny and Sleep Behavior: A Review. Unpublished manuscript, 1971.
- Flanigan, W. Behavioral States and Electroencephalograms of Reptiles. In M. Chase (Ed.), The Sleeping Brain, Brain Information Service/Brain Research Institute, Los Angeles: UCLA, 1972.

- Froberg, J., Karlsson, C., Levi, L. and Lidberg, L. Psychobiological Circadian Rhythms During a 72 Hour Vigil. Forsvarsmedicin, 1975, 11, 192-201.
- Gagnon, P., and De Koninck. Reappearance of EEG Slow Waves in Extended Sleep. Sleep Research, 1981 (in press).
- Gesell, A., and Amatruda, C. The Embryology of Behavior, New York: Harper, 1945, pp. 144-159.
- Globus, G. Rapid Eye Movement Cycle in Real Time. Arch. Gen. Psychiat., 1966, 15, 654-659.
- Heron, W. The Pathology of Boredom. Scientific Amer., January, 1957, 1, 430-436.
- Johns, M., Gay, T., Goodyear, M. and Masterton, J. Sleep Habits of Healthy Young Adults: Use of a Sleep Questionnaire. Brit. J. Prev. Soc. Med., 1971, 25, 236-241.
- Kleitman, N. Sleep and Wakefulness, Chicago: University of Chicago Press, 1963.
- Kleitman, N., and Engelmann, T. Sleep Characteristics of Infants. J. Applied Physiology, 1953, 6, 269-282.
- Kleitman, N., Mullin, F., Cooperman, N. and Titelbaum, S. Sleep Characteristics, Chicago: University of Chicago Press, 1937.
- Lewis, H. Sleep Patterns on Polar Expeditions. In G. Woistenholme and M. O'Connor (Eds.), CIBA Foundation Symposium on the Nature of Sleep, pp. 322-328, London: J. and A. Churchill, 1961.
- Lewis, H., and Masterton, J. Sleep and Wakefulness in the Arctic. Lancet, 1957, 1, 1262-1266.
- Maron, L., Rechtschaffen, D. and Wolpert, B. Sleep Cycle During Napping. Arch. Gen. Psychiat., 1964, 11, 503-508.
- Moses, J., Hord, D., Lubin, A., Johnson, L. and Naitoh, P. Dynamics of Nap Sleep During a 40 Hour Period. Electroenceph Clin. Neurophysiol., 1975, 39, 627-633.
- Moses, J., Lubin, A., Johnson, L. and Naitoh, P. Rapid Eye Movement Cycle is a Sleep-Dependent Rhythm. Nature, 1977, 265(5592), 360-361.
- Murry, E., Williams, H. and Lubin, A. Body Temperature and Psychological Ratings During Sleep Deprivation. J. Exp. Psychology, 1958, 56(3), 271-274.

- Nakagawa, Y. Continuous Observation of EEG Patterns at Night and in Daytime of Normal Subjects Under Restrained Conditions I. Quiescent State When Lying Down. Electroenceph. Clin. Neurophysiol., 1980, 49(5-6), 524-537.
- Parmelee, A., Wenner, W. and Schulz, H. Infant Sleep Patterns From Birth to 16 Weeks of Age. J. Pediatr., 1964, 65, 576-582.
- Potter, W., and Heron, W. Sleep During Perceptual Deprivation. Brain Research, 1972, 40, 534-539.
- Richter, C. R. Biological Clocks in Medicine and Psychiatry, Springfield, Illinois: C. C. Thomas, 1965.
- Ryback, R., and Lewis, O. Effects of Prolonged Bed Rest on EEG Sleep Patterns in Young, Healthy Volunteers. EEG and Clinical Neurophysiol., 1971, 31, 395-399.
- Ryback, R., Lewis, O. and Lessard, C. Psychobiologic Effects of Prolonged Bed Rest (Weightless) in Young, Healthy Volunteers (Study 2). Aerospace Medicine, 1971, 42(5), 529-535.
- Salzarulo, P., Fagiolo, I., Salomon, F., Ricour, C., Raimbault, G., Ambrosi, S., Cicchi, V., Duhamel, J. and Rigoard, M. Sleep Patterns in Infants Under Continuous Feeding From Birth. EEG and Clin. Neurophysiol., 1980, 49, 330-336.
- Sander, L., Stechler, G., Burns, P. and Julia, H. Early Mother-Infant Interaction and 24-Hour Patterns of Activity and Sleep. J. Am. Acad. Child. Psychiat., 1970, 9, 103-123.
- Snyder, F. Discussion in Chase, M. H., The Sleep Brain. Perspectives in the Brain Sciences, Brain Information Service/Brain Research Institute, Vol. 1, p. 45, Los Angeles: UCLA, 1972.
- Sterman, M. Ontogeny of Sleep: Implications for Function. In Drucker-Colin, Shkurovich and Sterman (Eds.). The Functions of Sleep, pp. 207-232, New York: Academic Press, 1979.
- Symposium on Quantitative Biology, Vol. XXV, Biological Clocks. Cold Springs Harbor, Long Island Cold Springs Harbor Symp., Quant. Biol., 1960, 25.
- Verdone, P. Sleep Satiation-Extended Sleep in Normal Subjects. Electroenceph. Clin. Neurophysiol., 1968, 24(5), 417-423.
- Webb, W. Twenty-Four Hour Sleep Cycling. In Kales, A. H. (Ed.), Sleep: Physiology and Pathology, pp. 53-65, Philadelphia: J. B. Lippincott Co., 1969.

- Webb, W. Sleep Behavior as a Biorhythm. In W. P. Colquhoun (Ed.), Biological Rhythms and Human Performance, pp. 149-178, New York: Academic Press, 1971.
- Webb, W. Sleep and Naps, Speculations in Science and Tech., 1978, 1(4), 313-318.
- Webb, W. Sleep Patterns in Older Males and Females. Research Comm. in Psychiatry, Psychology and Biology, 1981 (in press).
- Webb, W., and Agnew, H. Stage 4 Sleep: Influence of Time Course Variables. Science, 1971, 124, 1354-1356.
- Webb, W., and Agnew, H. Sleep and Waking in a Time-Free Environment. Aerospace Med., 1974a, 45(6), 617-622.
- Webb, W., and Agnew, H. Regularity in the Control of the Free-Running Sleep-Wakefulness Rhythm. Aerospace Med., 1974b, 45(7), 701-704.
- Webb, W., and Agnew, H. Are We Chronically Sleep Deprived? Bulletin of the Psychonomic Society, 1975, 6(1), 47-48.
- Webb, W., and Agnew, H. Sleep Efficiency for Sleep-Wake Cycles of Varied Length. Psychophysiol., 1975a, 6(1), 47-48.
- Webb, W., and Agnew, H. The Effects on Subsequent Sleep of an Acute Restriction of Sleep Length. Psychophysiol., 1975b, 12(4), 367-370.
- Webb, W., and Agnew, H. Analysis of the Sleep Stages in Sleep-Wakefulness Regimens of Varied Length. Psychophysiology, 1977, 14(5), 445-450.
- Webb, W., and Agnew, H. Effects of Rapidly Rotating Shifts on Sleep Patterns and Sleep Structure. Aviat. Space and Environ. Med., 1978, 49(2), 384-389.
- Webb, W., Agnew, H. and Sternthal, H. Sleep During the Early Morning. Psychonom. Sci., 1966, 6, 277-278.
- Webb, W., Agnew, H. and Williams, R. Effect on Sleep of a Sleep Period Time Displacement. Aerospace Med., 1971, 42(2), 152-155.
- Webb, W., Campbell, S. and Hendlin, R. The Termination of Extended Sleep. Biological Psychology, 1980, 11, 45-48.

- Weitzman, E. Periodicity in Sleep and Waking States in Chase M. H. (Ed.), The Sleeping Brain, Perspectives in the Brain Sciences, Vol. 1, p. 45, Brain Information Service/Brain Research Institute, Los Angeles: UCLA, 1972.
- Weitzman, E., Nogueire, C., Perlow, M., Fukushima, P., Sassin, J., McGregor, P., Gallagher, T. and Hellman, L. Effects of a Prolonged 3-Hour Sleep-Wake Cycle on Sleep Stages, Plasma Cortisol, Growth Hormone and Body Temperature in Man. J. Clin. Endocrinol. Metab., 1974, 38, 1018-1029.
- Wever, R. Internal Phase-Angle Differences in Human Circadian Rhythms: Causes for Changes and Problems of Determinations. Int. J. Chronobiology, 1973, 1, 371-390.
- White, R. Sleep Length and Variability: Measurement and Interrelationships. PhD Dissertation, University of Florida, 1975.
- Williams, R., Agnew, H. and Webb, W. Sleep Patterns in Young Adults: An EEG Study. Electroenceph. Clin. Neurophysiol., 1964, 17, 376-381.
- Williams, R., Agnew, H. and Webb, W. Sleep Patterns in Young Adult Females: An EEG Study. Electroenceph. Clin. Neurophysiol., 1966, 20, 264-266.

BIOGRAPHICAL SKETCH

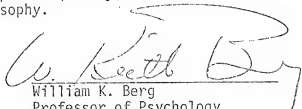
Scott Searcy Campbell was born February 25, 1952. He received his B.A. degree, with a major in psychology, from Florida State University in 1974. From September, 1972, to June, 1978, he attended Montana State University from which he received the M.S. degree in experimental psychology. In September, 1978, he continued his graduate studies, under the supervision of Wilse B. Webb, at the University of Florida. Upon completion of the Ph.D. degree, he accepted a postdoctoral fellowship at Harvard Medical School.

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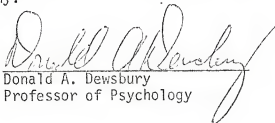
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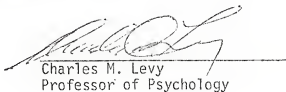
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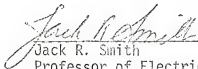
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A handwritten signature in cursive script, appearing to read "Jack R. Smith", is written over a horizontal line.

Jack R. Smith
Professor of Electrical
Engineering

This dissertation was submitted to the Graduate Faculty of the Department of Psychology in the College of Liberal Arts and Sciences and to the Graduate Council, and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

August 1979

Dean for Graduate Studies and
Research